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ON THE FEASIBILITY OF USING THERMISTORS TO MEASURE OCEAN CURREN--ETC(U)
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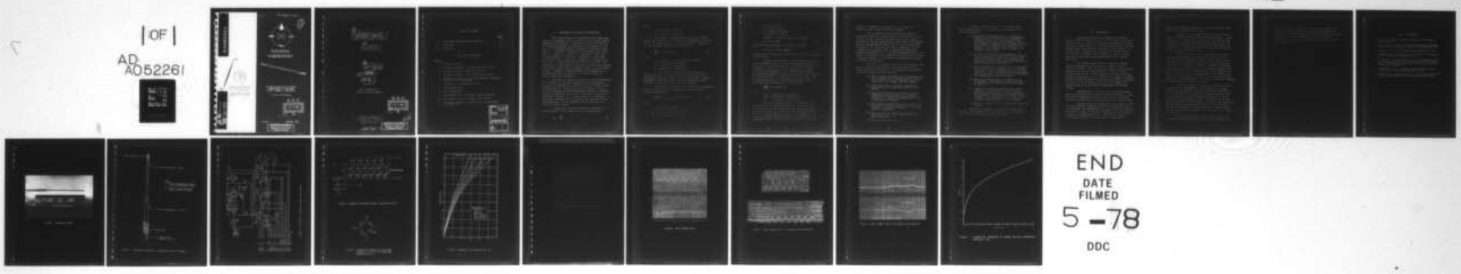

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DAVIDSON LABORATORY

STEVENS INSTITUTE OF TECHNOLOGY

CASTLE POINT STATION
HOBOKEN, NEW JERSEY

ON THE FEASIBILITY OF USING THERMISTORS TO MEASURE OCEAN CURRENT VELOCITIES

by Joel W. Hollenberg

N-642 JANUARY 1962

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SIT-DL-N-

Note 642

11 January 1962

12 22p.

Work Supported by
Office of Naval Research

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Castle Point Station
Hoboken, New Jersey

104750

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I. THEORETICAL AND DESIGN CONSIDERATIONS

The characteristic of thermistors which makes them useful for measuring fluid velocities is their large negative temperature coefficient of resistance, which can be as high as -5.8 percent/degree centigrade at room temperature, compared to 0.30 percent/degree centigrade for platinum (reference 1). A thermistor immersed in a stationary fluid can be heated by means of a current to a temperature higher than its surroundings. Thus it will lose heat by steady-state convection. When a thermistor is exposed to a moving stream of fluid, it loses further heat by forced convection. The temperature of the thermistor and hence its resistance depends on the fluid velocity and temperature as well as the heating current. Assuming a constant ambient fluid temperature, a relationship exists between the fluid velocity and the voltage across the thermistor.

The velocity can be determined by either maintaining the thermistor at constant temperature and adjusting the current, or by heating the thermistor with a constant current and measuring the voltage drop in the thermistor circuit. For fast response, constant-temperature operation is superior because it diminishes the effect of time lags caused by the thermistor (reference 2). Current required for constant-temperature operation can be adjusted with appropriate feedback amplifiers, and the adjustment may be read out as a change in bridge voltage.

Considering constant-temperature operation, the power supplied to the thermistor can be expressed as:

$$P_{in} = \frac{V_T^{\,2}}{R_T} \tag{1}$$

where

V_T = thermistor voltage

R_T = thermistor resistance

In constant-temperature operation, R_T is constant and V_T can be measured. This power is dissipated in the form of heat and carried away by the moving stream. Therefore, an energy-balance equation can be written as

$$\frac{V_T^2}{R_T} = h_c A(T_T - T_a) \tag{2}$$

where

h_c = convective heat transfer coefficient

A = thermistor surface-area

T_T = thermistor temperature

T_a = ambient-fluid temperature

If the thermistor temperature distribution is assumed to be uniform and constant, its resistance can be determined using data supplied by the manufacturer. Because the ambient-fluid temperature and the surface area of the thermistor are known, h_c only must be determined.

Considering the thermistor as a sphere, an expression involving h_c for Reynolds numbers less than 2000 can be written (reference 3):

$$\frac{h_c d}{k_f} Pr_f^{-0.3} = 0.97 + 0.68 \, Re^{0.5} \tag{3}$$

where

d = thermistor diameter

k_f = fluid thermal-conductivity

Pr_f = fluid Prandtl-number

Re = Reynolds number = $\rho \frac{Vd}{\mu}$

ρ = fluid density

V = fluid velocity

d = thermistor diameter

μ = fluid viscosity

Equation 3 solved in terms of h_c yields,

$$h_c = A + B \sqrt{V} \tag{4}$$

and substituting equation 4 in equation 1 yields

$$V_T = [(C + D \sqrt{V}) (R_T \Delta T)]^{0.5} \tag{5}$$

using ΔT for the temperature difference between the thermistor and the fluid.

R_T and ΔT are constants in a constant temperature mode of operation, and the voltage is proportional to the one-fourth power of the velocity in the Reynolds number range considered. Therefore, V_T can be increased at constant velocity by increasing R_T or ΔT. However, they cannot be increased simultaneously, because an increase in R_T will cause ΔT to decrease due to the properties of thermistors. The relationship between the resistance and temperature of a thermistor may be expressed as (reference 1):

$$\frac{R(T)}{R(T_o)} = \exp \beta\left(\frac{1}{T} - \frac{1}{T_o}\right) \tag{6}$$

where

$R(T)$ = resistance at temperature T

$R(T_o)$ = resistance at temperature T_o

β = a constant of the material

The best operating point of a thermistor can be found--that is, the largest voltage can be obtained for a given velocity by substituting for R_T, in equation 5, its value in terms of T_T and T_a. The resulting relationship between V_T and T_T can be differentiated to find a maximum for V_T. This sets the best operating point of the thermistor. Using appropriate values for the various quantities in equations

5 and 6, a temperature difference of 50°F between the thermistor and the water yields a maximum V_T.

For the velocity probe developed at Davidson Laboratory, equation 5 can be used for velocities up to 4.5 feet per second. Figure 10 shows the solution of V_T as a function of velocity obtained from these theoretical considerations using appropriate values for the various quantities. The shape of the curve and the order of magnitude of the voltage are in agreement with our previous experimental experience (reference 2). To extend measurements beyond this region, a knowledge of heat transfer from spheres in the range of Reynolds numbers of interest and an experimental program of testing are necessary.

The use of thermistors as fluid velocity meters has been tried by others as well as Davidson Laboratory with moderate success (reference 2). At present, the main difficulties encountered in their use are:

(a) Their inherent nonlinearity--the signal produced by a thermistor is a function of the velocity to the one-fourth power, depending on forced convective heat transfer and flow regime.

(b) Their sensitivity to ambient temperatures (reference 4)--an intrinsic property of the device.

(c) Their interaction with a conducting fluid--supplying electrical power to a thermistor in sea water requires either insulating the thermistor to prevent electrolysis or the use of alternating currents.

(d) Their general insensitivity to flow direction (reference 5)--the cooling effect of the fluid velocity is generally independent of the thermistor's orientation.

(e) Their tendency to change in characteristic during use. (This is a problem of hot-wire anemometry also).

(f) Their physical fragility.

However, continuing efforts to eliminate these difficulties have met with moderate success and may be summarized as follows:

(a) The inherent nonlinearity in the thermistor response can be compensated for by appropriate electronic circuitry. A diode linearizing (reference 5) circuit can be used to rectify the thermistor response or a nonlinear amplifier can be used to compensate the thermistor nonlinearity or both may be used together. In addition, the thermistor can be operated over a limited linear range.

(b) Corrections for ambient temperature can be achieved by using a second thermistor to measure the fluid temperature near the velocity thermistor, whose response at various ambient temperatures under a constant operating temperature can be determined by calibration.

(c) The thermistor can be shielded from a conducting fluid by coating the material with a thin layer of glass at a cost in response time or sensitivity or both. Time constants less than one second and resolutions of 0.01 ft/sec at low velocities have already been achieved in water.

(d) Direction sensing arrays of thermistors can be designed. This has been tried in air and in water to a very limited extent (references 5, 6, and 7).

(e) Changes in thermistor characteristics due to changes in the thermistor itself while in operation can be avoided by proper seasoning of the thermistor (reference 1). Changes caused by deposition of material from sea water on the surface of the thermistor can be reduced by a flushing or cleaning device on the sensor.

(f) Physical fragility can be decreased by structural design.

Therefore, thermistors, despite development difficulties, can be reliable fluid velocity meters, assuming in water the role filled by the hot wire in air.

II. BACKGROUND

Davidson Laboratory has developed a thermistor velocity meter to measure bottom velocities under ocean swell (Figures 1 and 2), which has been used successfully to measure fluctuating velocities up to 0.2 ft/sec peak and has withstood several days of intermittent operation in water depths of up to forty feet. Deposits on the thermistor surface during this time did not appear, and handling the probes required only those precautions normally associated with a fragile instrument.

The voltage output from the thermistor has been amplified, linearized, and written out using the circuit shown in Figure 3. Diode linearizing circuits have also been designed but have not yet been tested. Figure 3 shows a typical diode circuit. These linearizing circuits have been designed (reference 5) for velocities in the range of interest and can be made to linearize an input as accurately as desired by dividing the thermistor output curve into smaller and smaller steps and by providing an appropriate diode bias-voltage.

Temperatures of the fluid near the velocity sensor have been measured with a second thermistor (Figure 4). When the ambient temperature is known, the correct calibration curve can be selected for the reduction of the velocity data.

Figure 5 shows the calibration of the velocity probe at various ambient temperatures for our oceanographic work. The thermistor was calibrated by towing the probe at different velocities in water of different temperatures. Figure 6 shows a sample of oceanographic data. Figure 6 was recorded off Block Island in August 1961 and shows the simultaneous

recording of pressure, temperature, and velocity at a point under a wave near the ocean bottom.

Figure 7 shows a trace taken in a wave channel to check the accuracy of the thermistor velocity-meter. Surface elevation was recorded as a function of time and the peak velocity was computed using shallow water wave theory. By examining the velocity record obtained, the peak amplitude of velocity was found to be within 3 percent of the computed value of approximately 0.5 ft/sec.

Figure 9 shows a trace obtained during an experiment in a wave channel to determine the phase lag (time constant) of the thermistor. A single wave of short period was generated. The thermistor and a wave-height indicator, which used a styrofoam flat linked to a rotary differential transformer, were positioned in the same plane perpendicular to the wave front. The thermistor was in the potential flow region outside the bottom boundary-layer. By comparing the response of the thermistor to that of the wave-height indicator, a close approximation of the time constant was obtained, which was between 0.5 and 0.9 seconds.

As we are presently using them to measure velocity, thermistors are insensitive to flow direction. However, arrays could be designed that would indicate the direction of flow (reference 5). Experiments have been carried out at Davidson Laboratory using a single thermistor as a planar velocity direction finder in water. Figure 8 shows a data trace obtained in the wave channel. The probe was aligned with the flow and provided a varying signal as it was rotated through 180 degrees. In a fixed position, a varying signal was also obtained corresponding to the sense of the velocity of the wave.

The possible range of velocity measurement using thermistors can be increased by using larger themistors with

larger power input, up to several hundred milliwatts, or by providing circuits that accept the widely varying signal produced by a thermistor over a wide velocity range. Recently, experiments have been performed that showed thermistor response up to 3 ft/sec, and their response probably can be extended further.

III. REFERENCES

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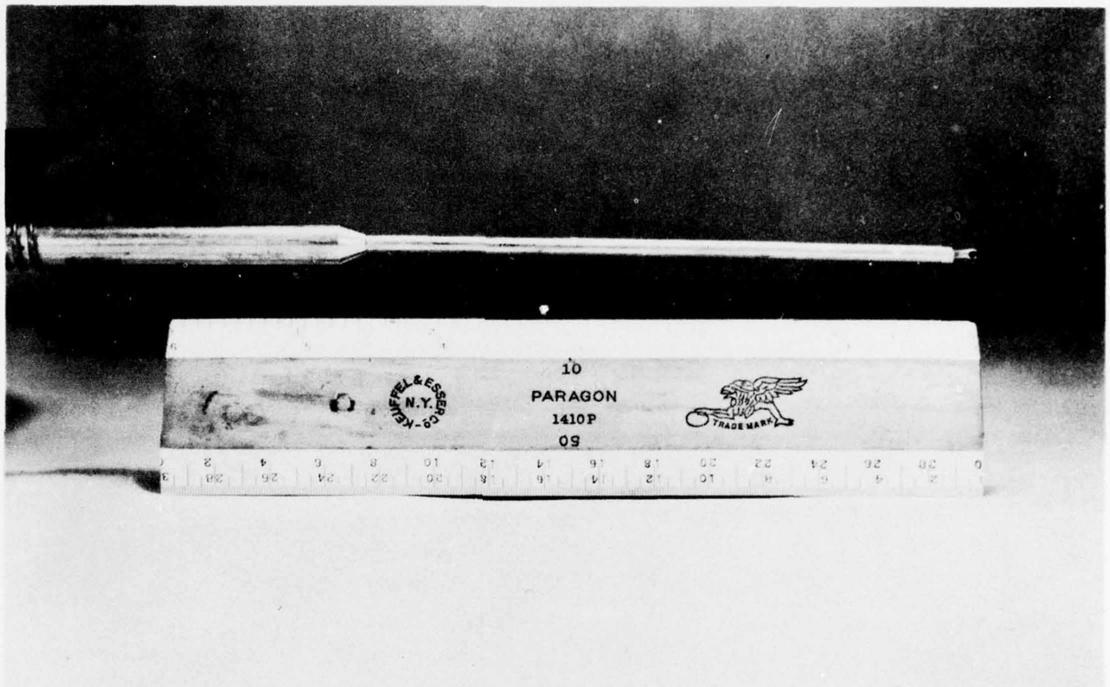


FIGURE I. THERMISTOR PROBE

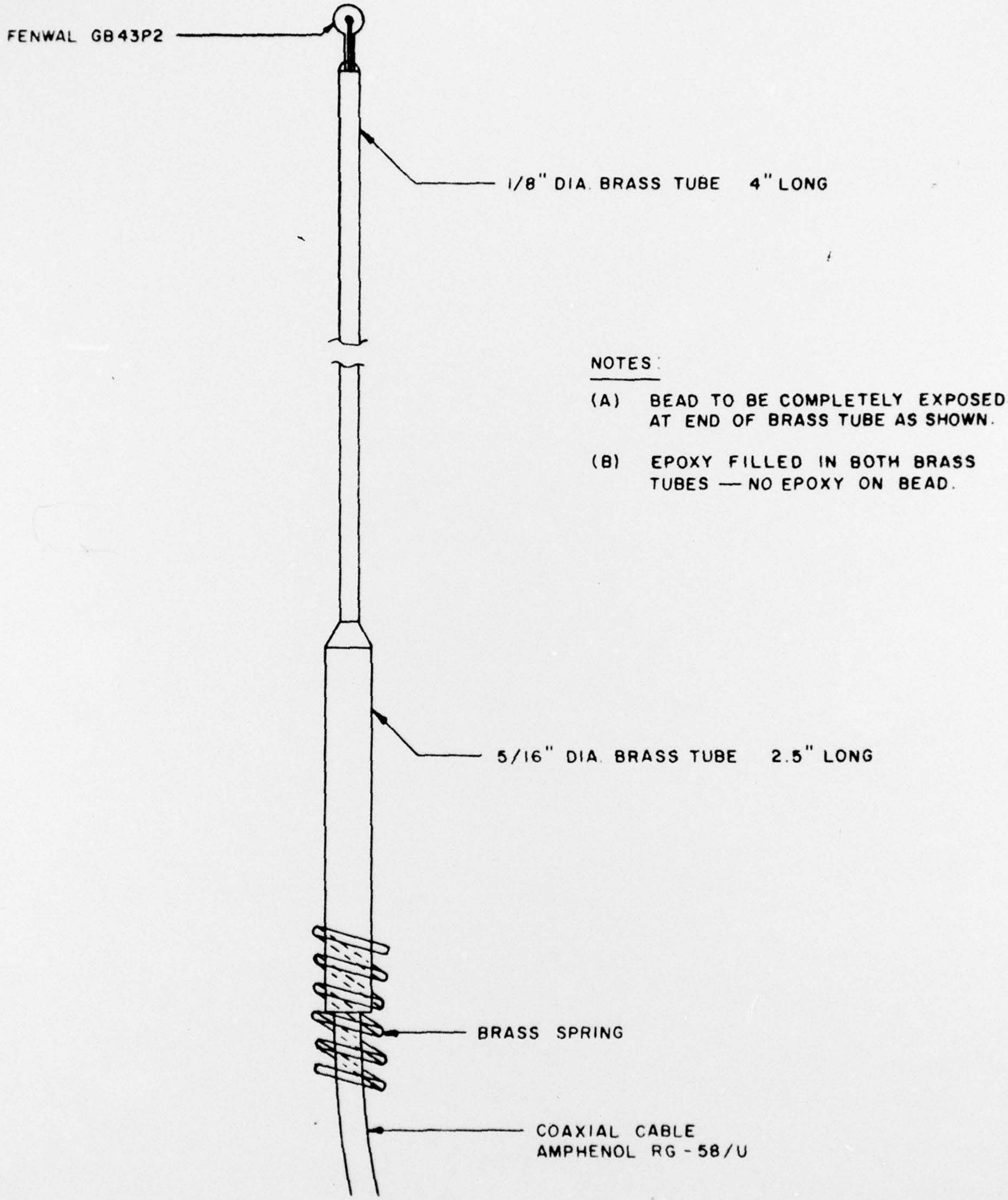


FIGURE 2. MECHANICAL DRAWING OF THERMISTOR VELOCITY-PROBE

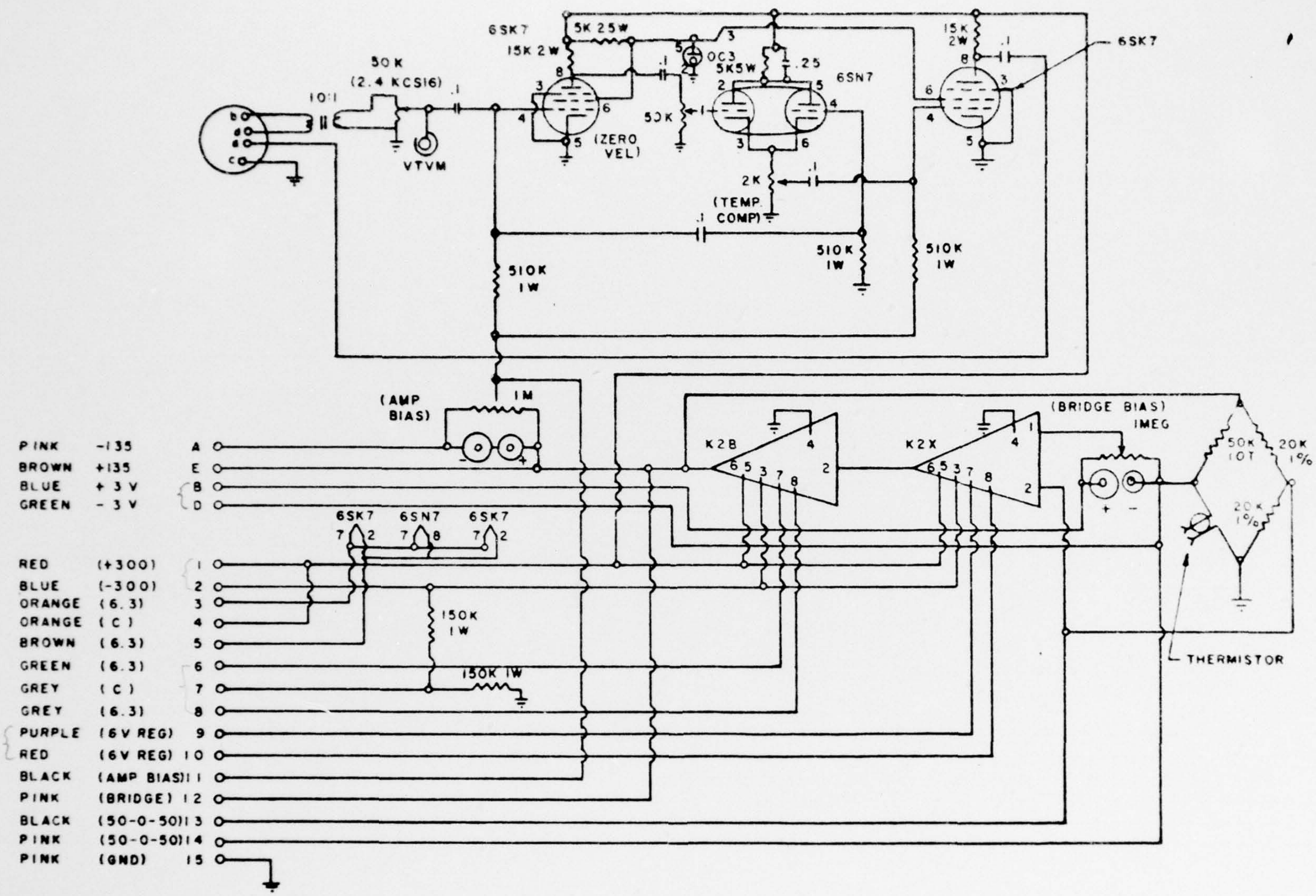


FIGURE 3. SCHEMATIC DIAGRAM OF AMPLIFIER CIRCUIT

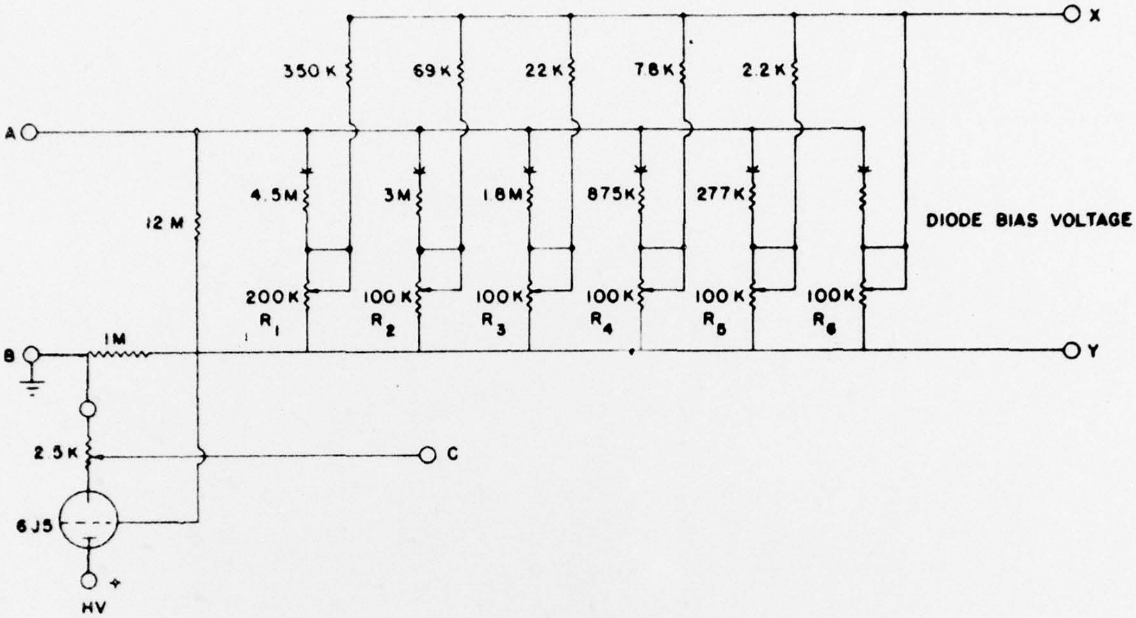


FIGURE 4. SCHEMATIC DIAGRAM OF DIODE LINEARIZING CIRCUIT

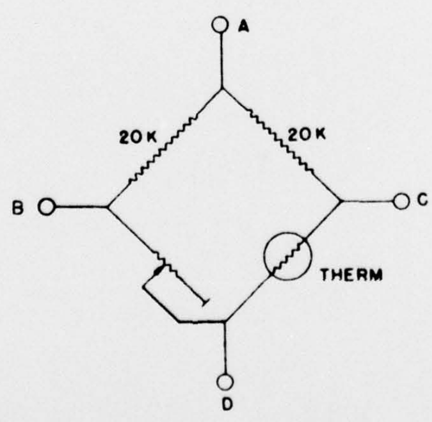


FIGURE 5. TEMPERATURE BRIDGE FOR 2000 OHM THERMISTOR (PINS ARE LETTERED FOR SANBORN INPUT)

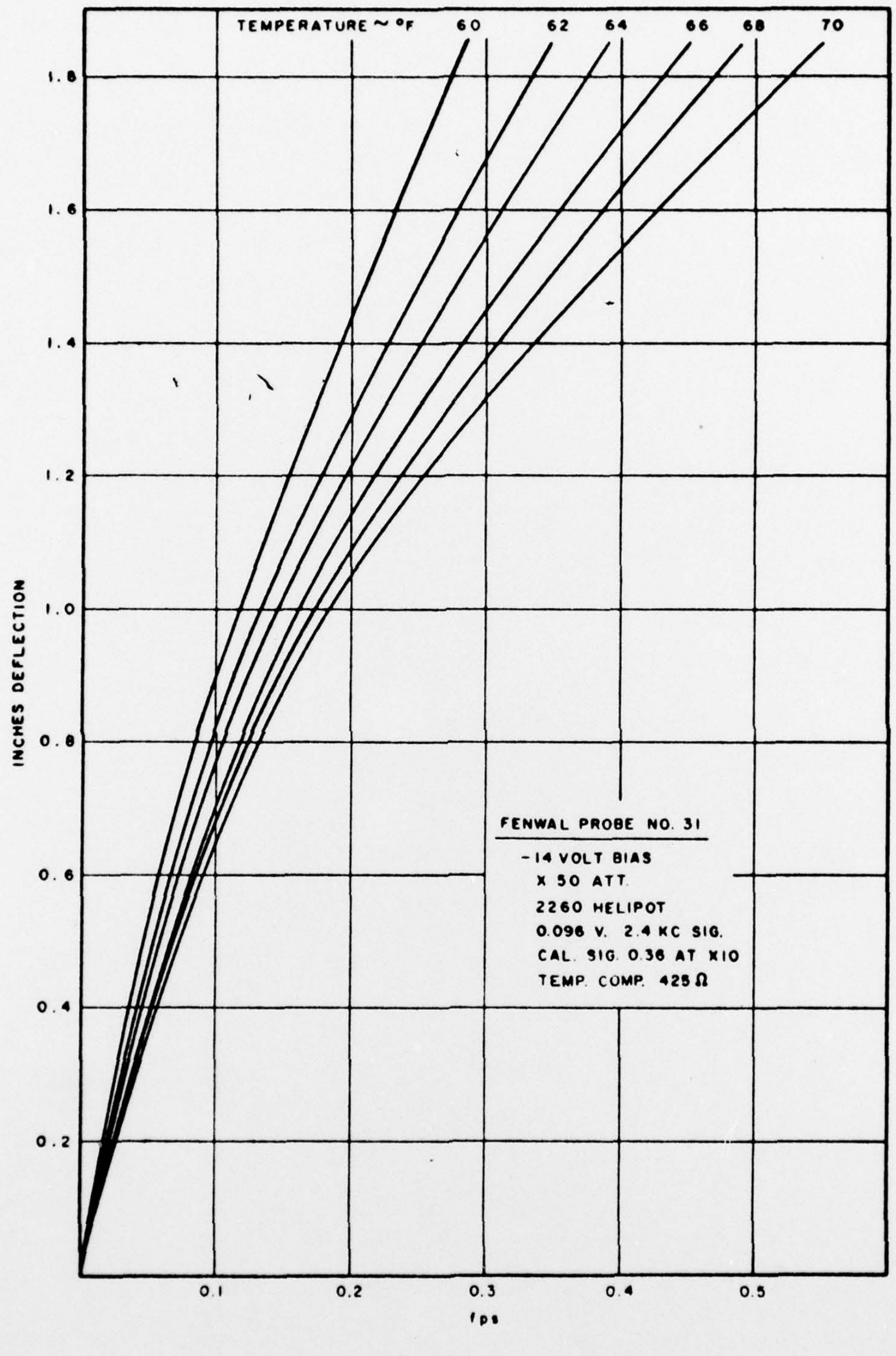


FIGURE 6. CALIBRATION FOR OCEANOGRAPHIC USE

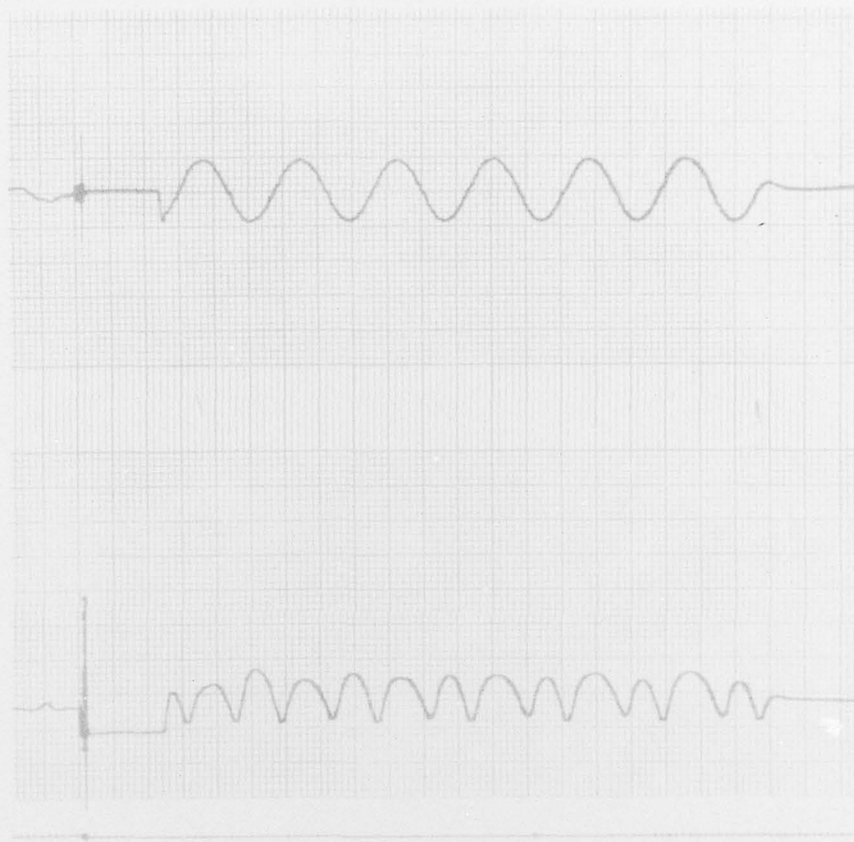


FIG. (7): WAVE CHANNEL DATA TAKEN TO CHECK ACCURACY

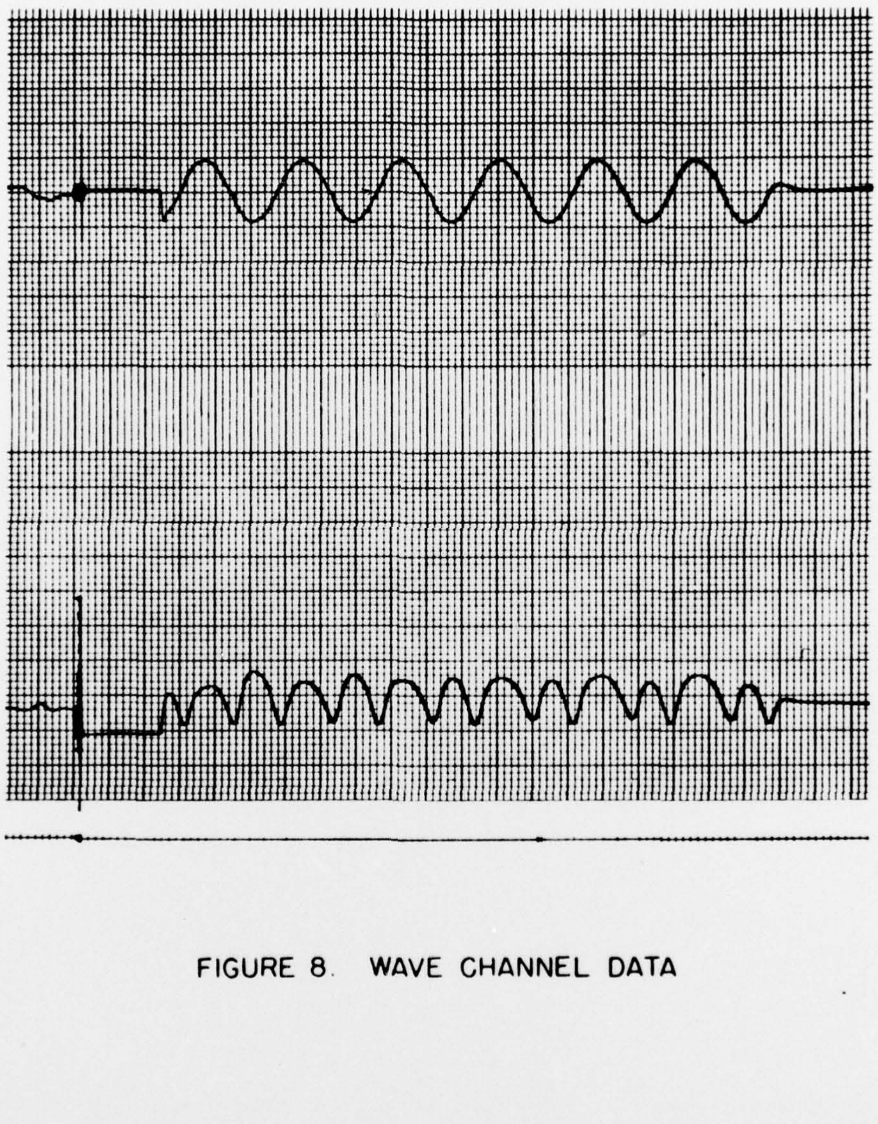
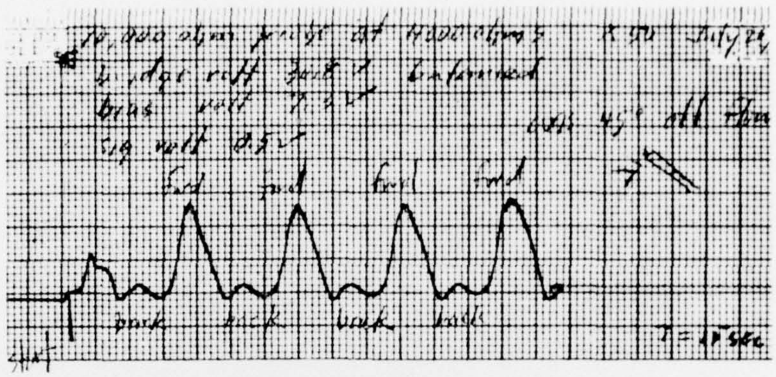


FIGURE 8. WAVE CHANNEL DATA



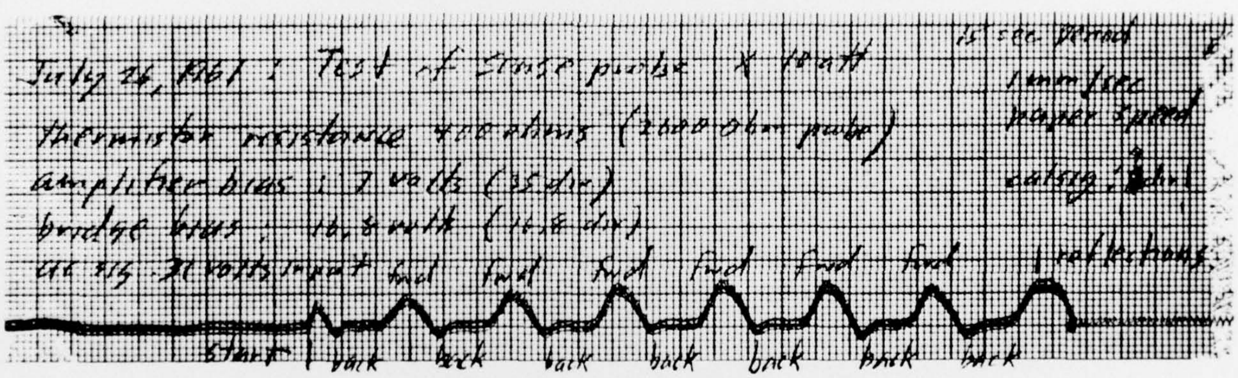


FIGURE 9. WAVE CHANNEL DATA TO DETERMINE SENSE INDICATION

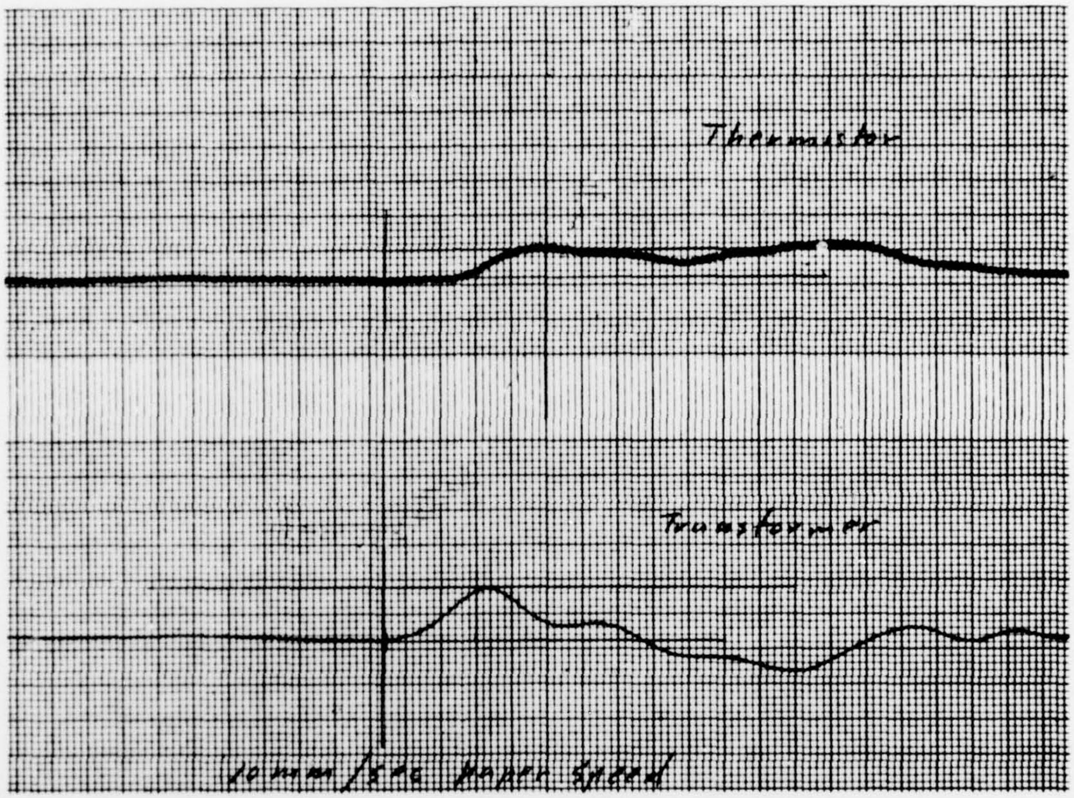


FIGURE 10. WAVE CHANNEL DATA TO DETERMINE TIME CONSTANT

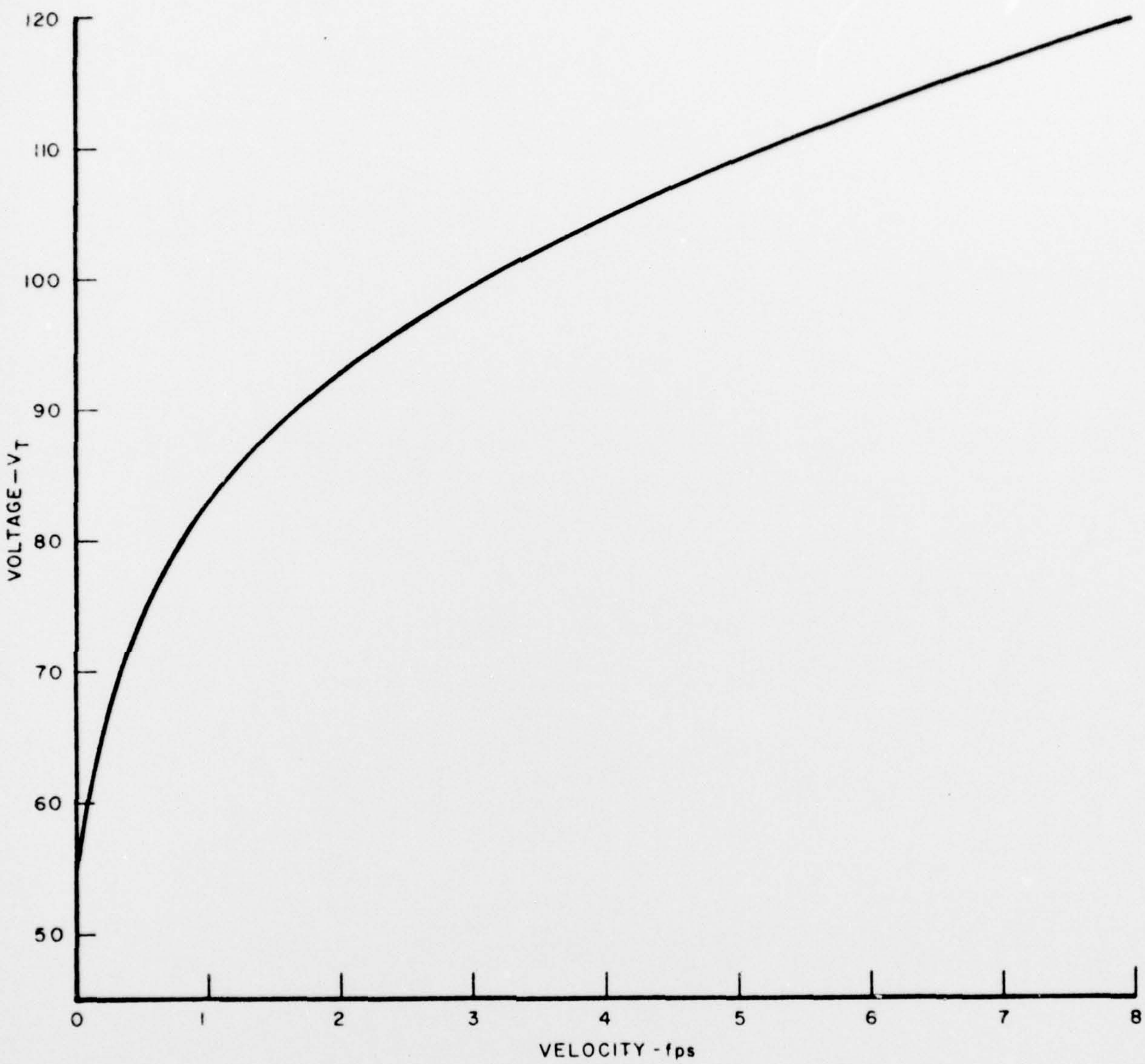


FIGURE 11. THEORETICAL RESPONSE OF FENWAL GB 43 p 2 THERMISTOR WITH $R\Delta T \sim 10^6$